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TECHNICAL REPORT AFATL-TR-73-67

# FREE FLIGHT TESTS OF S-CURVE BOMBLETS

Paul C. Mayer, Lt, USAF
GUN RANGE OPERATIONS BRANCH
GUNS AND ROCKETS DIVISION

MARCH 1973

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13. ABSTRACT

Free flight and impact pattern data were obtained for three types of S-curve bomblets launched singly and in clusters from a low pressure air gun. The tests were conducted to check impact patterns and possible interaction among bomblets when fired in groups. The air gun was used as an economical means of simulating air drops. The bomblets were designed to obtain an S-shaped pitching moment versus angle of attack curve where the bomblet trims at a non-zero angle of attack. This produces a radial lift force which increases the amount of dispersion. Control groups of ballistic bomblets were used to compare the impact patterns.

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| Free Flight Data | | | | | | |
| Impact Pattern | | | | | | |
| Low-Pressure Air Gun | | | | | | |

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## PREFACE

This report contains impact pattern data from air gun tests of the S-Curve bomblet conducted in support of Project 2547 from October to December 1972. The tests were conducted by the Gun Range Operations Branch, Guns and Rockets Division, at the Ballistic Aerodynamics Research System (BARS) Facility, Test Areas A22 and B82, Air Force Armament Laboratory, Eglin Air Force Base, Florida.

This technical report has been reviewed and is approved.

DALE M. DAVIS
Director, Guns and Rockets Division



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## INTRODUCTION

A series of air gun tests was conducted to generate impact patterns using three possible designs of S-curve bomblets. This new self-dispersing bomblet concept utilizes passive control of the radial orientation of the trimmed lift force to give large impact areas.

The distinguishing feature of an S-curve bomblet configuration is the shape of its static pitching moment coefficient curve (Figure 1) as a function of the angle of attack ( $\alpha$ ) (Reference 1). It is asymmetric about zero $\alpha$ and has a positive slope (unstable) for small values of $\alpha$ and a negative slope (stable) at larger values. It is invariant with roll angle. The two stable conditions occur where the curve crosses the axis with a negative slope. Dispersion of the bomblets occurs because of the lift generated at this stable trimmed condition.

Three major factors contribute to the shape of the pitching moment curve; basic body shape, tail fin area, and center of gravity location. One variant in body shape that will affect the curve is nose tip shape. Blunt noses with sharp edges tend to keep the center of pressure near the body center while rounded or pointed noses keep it well forward. The change in the center of pressure will affect the pitch stability, which depends on the relative positions of the center of pressure and the center of gravity. If the center of pressure is forward of the center of gravity, it is stable and, if aft, unstable.

Unlike changes in the nose shape, changes in the afterbody shape significantly alter the normal force as well as the center of pressure. This test considered the boattail afterbody as a possible configuration. The normal force decreases with a boattail afterbody (Reference 2) as compared with a straight afterbody, but this does not lead to a corresponding decrease in the pitching moment. The net effect is that the boattail decreases the stability of the body because the center of pressure actually occurs ahead of the body, and no change in the center of gravity will make the body stable. In this case, it is necessary to modify the fin configuration to increase the stability.

The fins on the S-curve bomblets are to have a low aspect ratio to reduce the induced roll moments at angle of attack, and the bomblets are to have a sufficient number of fins equally spaced around the body to retain a high degree of axial symmetry. The effect of the fins on the pitching moment is a moment generated by the normal force on the fins acting through a moment arm defined by the positions of the center of gravity and the center of pressure of the fins. Fins aligned parallel to the body axis will produce only positive normal forces and therefore can only increase stability. In order to maintain the S-shaped moment curve, a certain amount of static instability is required near zero $\alpha$ . The fins must then be small enough that the tail effect does not exceed the body effect at small $\alpha$ .

From a packaging standpoint, it may not always be possible to build-in the necessary forward center of gravity location. A center of gravity near the geometric center of the body is more reasonable. The position of the center of gravity then becomes the least flexible means of affecting the stability.

These tests were divided into three parts. The first part consisted of testing the S-curve theory against a control group to obtain the desired larger impact patterns. The second part

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References:

1. Brunk, J. E.: Aerodynamic Dispersion Techniques. AFATL-TR-70-123, Air Force Armament Laboratory, Eglin Air Force Base, Florida, November 1970 (Unclassified).
2. Brunk, J. E.: Flight Dynamics and Dispersion Characteristics of S-Curve and Roll-Through-Zero Bomblets. AFATL-TR-72-18, Air Force Armament Laboratory, Eglin Air Force Base, Florida, January 1972 (Unclassified).

was to test the ability to launch the S-curve bomblets in clusters and to test the stability of the boattail configuration. The third part tested the effects of a large diameter/length ratio, the fin size and the large cluster interactions.

## APPARATUS

### TEST AREA

Test Area B-82 on the Eglin AFB Reservation was used as the test site for the air gun shots. The test site consisted of an enclosed asphalt grid, 6000 feet long and 1000 feet wide. The grid was marked with wooden plates located every 100 feet in both directions. The gun placement and target area is shown in Figure 2. The asphalt surface was 1/2 inch thick with a soft clay underbase to give a well defined impact point and to provide easy spotting and recovery of the test item.

### TEST EQUIPMENT

Figure 3 shows the low pressure air gun in the firing position being muzzle loaded with one of the test items. Safety shields were used on three sides to protect personnel. The gun was anchored using 4 foot anchor rods and 1/4 inch steel cable, The barrel is 10 feet long with an inside diameter of 5.5 inches and was elevated to 30 degrees from the horizontal to provide an impact angle that closely simulated an air drop. The gun was operated at 135 pounds per square inch chamber pressure and was charged with nitrogen from portable gas cylinders. The gun is manually fired with a lanyard.

### TEST ARTICLES

Each of the three segments of the test contained several different test item configurations. The 12 inch model (Figure 4) made up the first segment of the test which consisted of two model configurations. The first 29 models had the center of gravity located forward in the nose to prevent a trim angle of attack and therefore any additional lift force. This provided a control group which had an impact pattern that could be compared to the impact pattern of the S-curve models. The second group of 27 models (the S-curve models) had the center of gravity located 4.48 inches from the nose to provide a 7 degree trim angle of attack. Five additional S-curve models were given an intentional fin misalignment to test the effect on the pattern. Also, 10 of the S-curve models were recovered after launching and were re-flown to determine the effect of nose scratches and other asymmetrics on the impact pattern. All of the 12 inch models were launched singly with velocities averaging 370 ft/sec.

Two types of 6 inch S-curve models (Figure 5) were flown during the second segment of the test. The first type was a scaled-down version of the 12 inch model, while the second had the boattail afterbody. Five shots were made of each configuration in clusters of seven models. This segment tested the effects of firing in clusters, as well as the effect of the increased trimmed lift/weight ratio and the boattail configurations. These clusters were launched at 360 ft/sec.

The third segment of the test had three model configurations (Figure 6). The first was a plain cylinder to be used as a control group. The second and third model configurations differed only in fin size. These were launched in clusters of 14 and at an average velocity of 690 ft/sec. The purpose was to test the effect of a large diameter/length ratio, the fin size, and large cluster interactions.

All the test items were fitted in sabots before placing in the air gun, and the cluster items were packed in sawdust to keep them aligned before sabot separation. Trajectories were calculated for all test cases to determine the probable impact point for the models. Aerodynamic data used to generate these trajectories were taken from References 3 and 4.

## INSTRUMENTATION

The initial conditions recorded included the three components of position, velocity, and acceleration, as well as the azimuth and elevation angle velocity and acceleration. These data were recorded on high speed (1000 fps) film using four cameras located as shown in Figure 2. Camera 1 had a field of view of 36 feet and provided a documentatry film to show sabot separation and cluster breakup. Cameras 2, 3, and 4 were data recorders and had a field of view of 6 feet. One of the cameras used is shown in Figure 7. Boresight poles were mounted in front of the gun and were filmed prior to each day's firing to give references for data reduction.

Wind conditions were recorded before each shot and included speed and direction. Temperature and humidity were also recorded. Impact position was measured by range personnel and marked relative to the grid plates on the range. Each of the items were numbered to provide a correlation between initial conditions and the impact pattern.

# TEST DESCRIPTION

## TEST PROCEDURE

The procedure for conducting the free-flight test was divided into three parts: the pre-test check, the actual test, and the post-test check.

The pre-test check included camera preparation as well as air gun preparation. The cameras were set up, loaded with film, and used to photograph a sequence of boresight poles to provide initial distance reference. The control panel for operating all four cameras simultaneously was placed behind the safety shields, near the air gun operator. The gun was boresighted and then raised to 30 degrees elevation. The barrel mount bolts were inspected to assure they were tight, and the anchor cables were secured to keep the gun from moving. The sabots were test fitted to the barrel to prevent jamming when loaded. After the air hose connections were checked, the gun was pressurized to the maximum operating pressure and test fired without a test item in the barrel.

The test itself consisted of muzzle loading the test item and sabot, using a ramrod to assure its placement at the root of the barrel. The test area was cleared of personnel, and the chamber of the gun was pressurized. A verbal countdown was given, and the gun was fired manually by pulling the lanyard which opened the dump valve. Wind data were obtained during the countdown, and the cameras were activated 2 seconds prior to firing to allow them to reach normal operating speed.

The post-test check included inspecting the chamber to assure that no pressure remained, clearing the barrel of any obstructions, making sure the dump valve remained open, and clearing

References:

3. Anderson, C. F.: Static and Dynamic Stability Characteristics of Several Short, Blunt, Cylindrical Bomblet Models at Mach Numbers from 0.4 to 1.3, AEDC-TR-71-110, Arnold Engineering Development Center, Tennessee, June 1971 (Unclassified).
4. Shadow, T. O.: Transonic Static Stability Characteristics of Bomblet Munition Models Used in the Evaluation of the Zero-Coning Aerodynamic Dispersal Technique. AFATL-TR-71-144, (AEDC-TR-71-247), Air Force Armament Laboratory, Eglin Air Force Base, Florida, November 1971 (Unclassified)

the range of sabots. This was done prior to personnel entering the area in front of the safety shields. Cameras were checked, and the test item was scored and retrieved.

## PRECISION OF MEASUREMENTS

The test object was in the field of view of the data cameras for only a very short time, and the precision of any velocity or angle data could be questionable. Distortion due to edges of the camera lenses also reduced the amount of reliable data that could be obtained from the movies. The overall accuracy was not precise but reflected the trends for which the test was designed.

The precision of the measurements is as follows:

| Variable | Precision |
|---|---|
| Gun Location, ft | ± 1.0 |
| Velocity, ft/sec | ± 10 |
| Trajectory Angle, deg | ± 0.5 |
| Pitch Angle, deg | ± 2.0 |
| Yaw Angle, deg | ± 2.0 |
| Impact Scoring, ft | ± 1.0 |
| Wind Velocity, knots | ± 1.0 |
| Wind Direction, deg | ± 12.0 |

# RESULTS

## INITIAL CONDITIONS

The initial conditions measured were used as a basis for comparison between shots of the same test item. Effects of the S-curve motion could be determined by examining the initial angle of the test item to determine the trim angle of attack. Impact pattern deviations could also be explained if perturbations showed up in the first 50 feet of the trajectory. Velocity comparisons would explain possible "wild shots" shown on the impact patterns.

The representative data collected for the three segments of the test are shown in the following lists. Not all of the shots have been included since some data was lost due to camera malfunction. No angle data were derived for the cluster shots because of the lack of camera clarity for the small items. In all cases, the wind data proved to have little or no effect on the impact patterns. The wind velocities taken during each shot rarely exceeded 4 knots and therefore were neglected as a possible cause for pattern deviations.

## INITIAL DATA FOR 12-INCH MODELS (SINGLE SHOTS)

| DATA | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SHOT NUMBER | | | | | | |
| 1. BALLISTIC DATA | | | | | | | | | | |
| Velocity, ft/sec | 371 | 346 | 346 | 348 | 376 | 374 | 369 | 359 | | |
| Pitch Angle, deg | 37 | 42 | 24 | 33 | 21 | 34 | 35 | 27 | | |
| Yaw Angle, deg | 6 | 3 | -7 | -1 | 12 | 4 | 2 | -3 | | |
| 2. S-CURVE | | | | | | | | | | |
| Velocity, ft/sec | 361 | 382 | 373 | 365 | 364 | 388 | 385 | 387 | | |
| Pitch Angle, deg | 34 | 35 | 30 | 27 | 31 | 36 | 25 | 23 | | |
| Yaw Angle, deg | 5 | 9 | 3 | 7 | 18 | 5 | 10 | -16 | | |
| 3. BENT FIN | | | | | | | | | | |
| Velocity, ft/sec | 373 | 375 | 372 | 373 | 367 | | | | | |
| Pitch Angle, deg | 22 | 28 | 32 | 30 | 33 | | | | | |
| Yaw Angle, deg | 18 | -8 | 8 | 3 | -10 | | | | | |
| 4. SCRATCHED NOSE | | | | | | | | | | |
| Velocity, ft/sec | 363 | 362 | 364 | 361 | 359 | 352 | 363 | 360 | 356 | 369 |
| Pitch Angle, deg | 35 | 24 | 31 | 53 | 33 | 35 | 26 | 23 | 46 | 32 |
| Yaw Angle, deg | 6 | 6 | 15 | -16 | 19 | 20 | 22 | -3 | 16 | 19 |

## INITIAL DATA FOR CLUSTER SHOTS

| MODEL | VELOCITY, ft/sec SHOT 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 6-inch Square End | 321 | 343 | 343 | -- |
| 6-inch Boattail | 358 | 362 | 367 | 364 |
| 2 1/4-inch Cylinder | 674 | 470 | -- | -- |
| 2 1/4-inch Large Fin | [a] 284 | 692 | -- | -- |
| 2 1/4-inch Small Fin | 705 | 691 | -- | -- |

[a]Gun Malfunctioned

## IMPACT PATTERNS

The test pattern for the ballistic (non-lifting) models (Figure 8) shows the small crossrange dispersion that would be expected if wind effects were minimal. The pattern is approximately 200 feet in width and 600 feet long. The one very short point was due to sabot failure during launch. The impact pattern for the standard S-curve bomblets (Figure 9) confirms the effectiveness of the dispersion concept; here the pattern has increased to approximately 600 feet in width and 1200 feet long.

The five examples of intentional fin misalignment are a very small sample group (Figure 10), and the data are not sufficient to show any effect in the pattern size using the roll induced by the bent fin. The 10 recovered S-curve bomblets that were reflown to determine the effect of nose scratches and other asymmetrics (dents, dirt clogs, etc ) indicate a moderate decrease in both the crossrange dispersion and in the range of flight (Figure 11).

Impact pattern results for the 6 inch cluster launched models are shown in Figures 12 and 13. The pattern generated by the boattail models was extremely large, while the square-end bomblet displays an alongated pattern with reduced crossrange dispersion, as compared with the larger scaled 12 inch models of the same body configuration. It has been anticipated (Reference 5) that the dispersion should increase in proportion to the trimmmed lift/weight ratio for the individual models. Thus, the patterns for the 6 inch models should be larger than for the 12 inch bomblets.

The impact patterns for the 2-1/4 inch models (plain cylinders and small and large finned models) all fell at the planned target center. This distance was approximately 1700 feet from the planned target center of the 12 inch models. This was due to a much higher trim angle of attack. the plain cylinders, which fell in a very close pattern (Figure 14) provided a control group to be used as a comparison for the small and large finned models. As was expected, these models showed very little if any dispersion. Aerodynamically, it was understood that these models would tumble during flight. The large finned models, for one of the two shots, showed much greater dispersion (Figure 15) than did the cylinders, but the crossrange dispersion was small compared to the downrange dispersion. The small finned models (Figure 16) generated a similar pattern to that of the cylinders, and little or no dispersion was evident. All of the 2-1/4 inch models were examined, after firing, to determine from the impact markings whether or not they were tumbling when they struck the ground. The number of marks counted on the head, side, and tail of the model is as follows:

| MODEL | NUMBER OF MARKS HEAD | SIDE | TAIL |
|---|---|---|---|
| Cylinder | 12 | 6 | 10 |
| Large Finned | 21 | 2 | 4 |
| Small Finned | 14 | 3 | 9 |

## CONCLUSIONS

Based on the results of this investigation of the S-curve bomblet, the following conclusions are drawn:

1. The S-curve theory proved to be valid with larger dispersion patterns being generated when utilizing the lift vector at a trim angle of attack.

2. Trim angle of attack data could not be obtained with any precision due to the fishtailing motion of the bomblets during the early stages of the trajectory. Angle data in the first 50 feet of flight looked the same for both ballistic and S-curve models.

3. Launching S-curve models in clusters of seven did not affect the dispersion or the range. An analyses of the test film showed little contact among the models during the initial portion of the flight even though the models were oriented in many directions after sabot separation.

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References
5. Brunk, J. E.: Monte Carlo Analysis of S-Curve and Roll-Through-Zero Bomblet Dispersion Characteristics. AFATL-TR-73-15, Air Force Armament Laboratory, Eglin Air Force Base, Florida, January 1973 (Unclassified).

4. The boattail configuration not only proved stable but also generated much larger impact patterns than the square end models.

5. The large diameter/length ratio bomblets gave little or no dispersion. The small fin model apparently tumbled. One of the large fin model clusters gave sufficient dispersion to indicate S-curve dispersal of short models may be feasible.

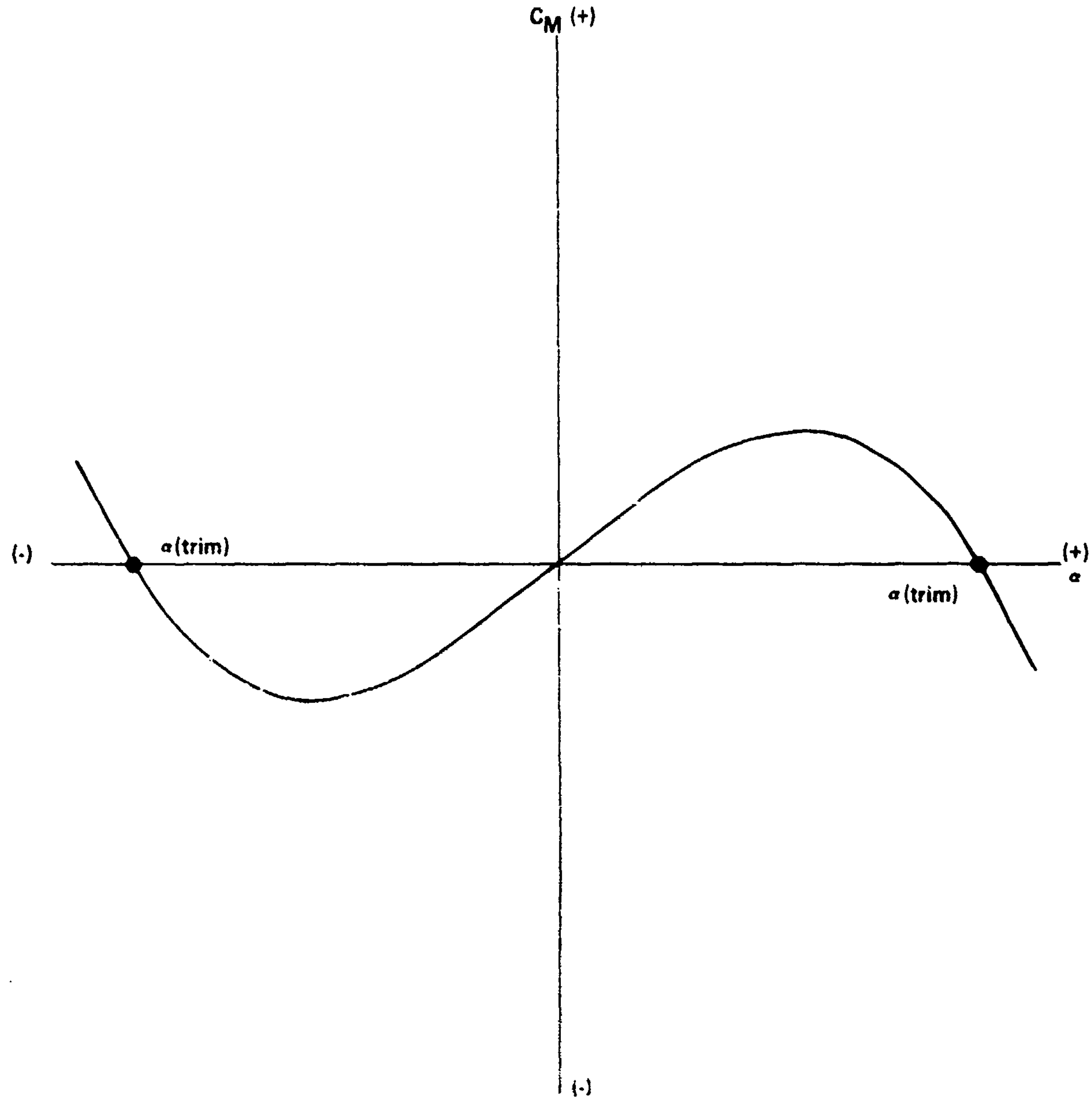


Figure 1. S-Curve Moment Variation

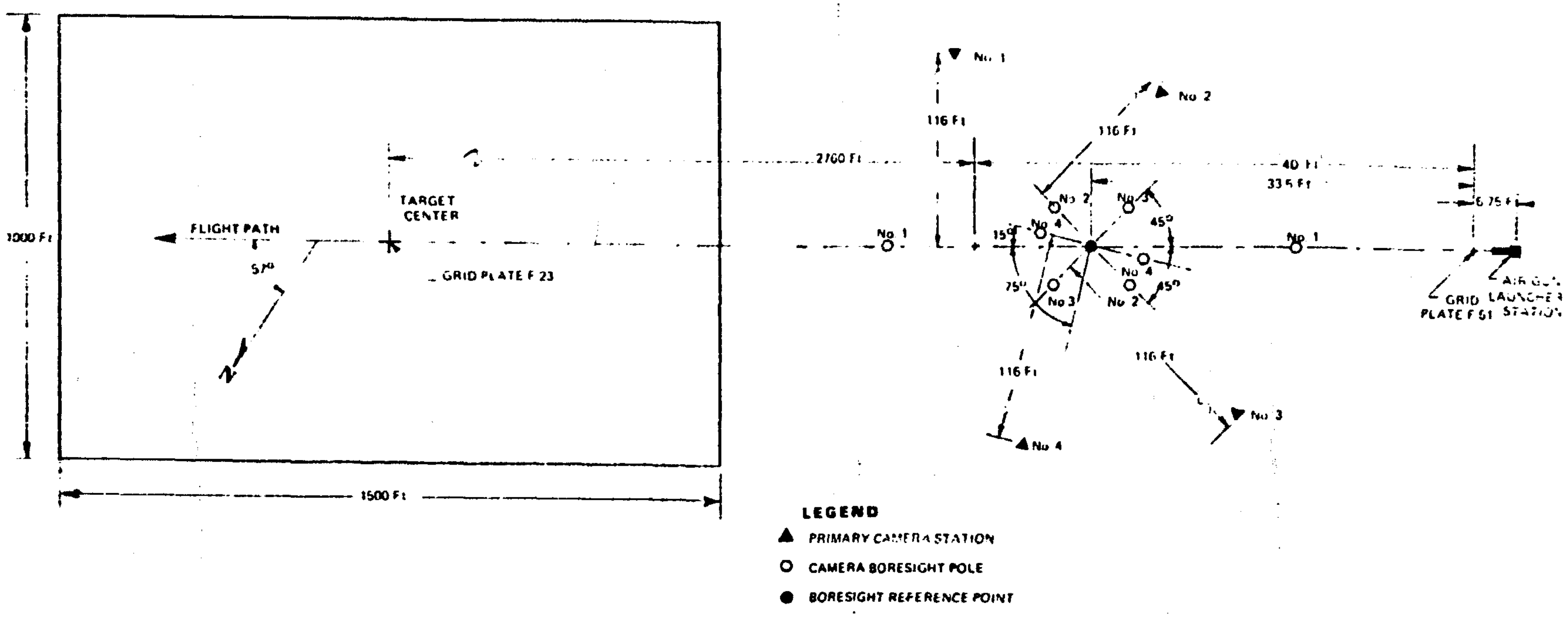


Figure 2. Gun, Camera, and Target Placement

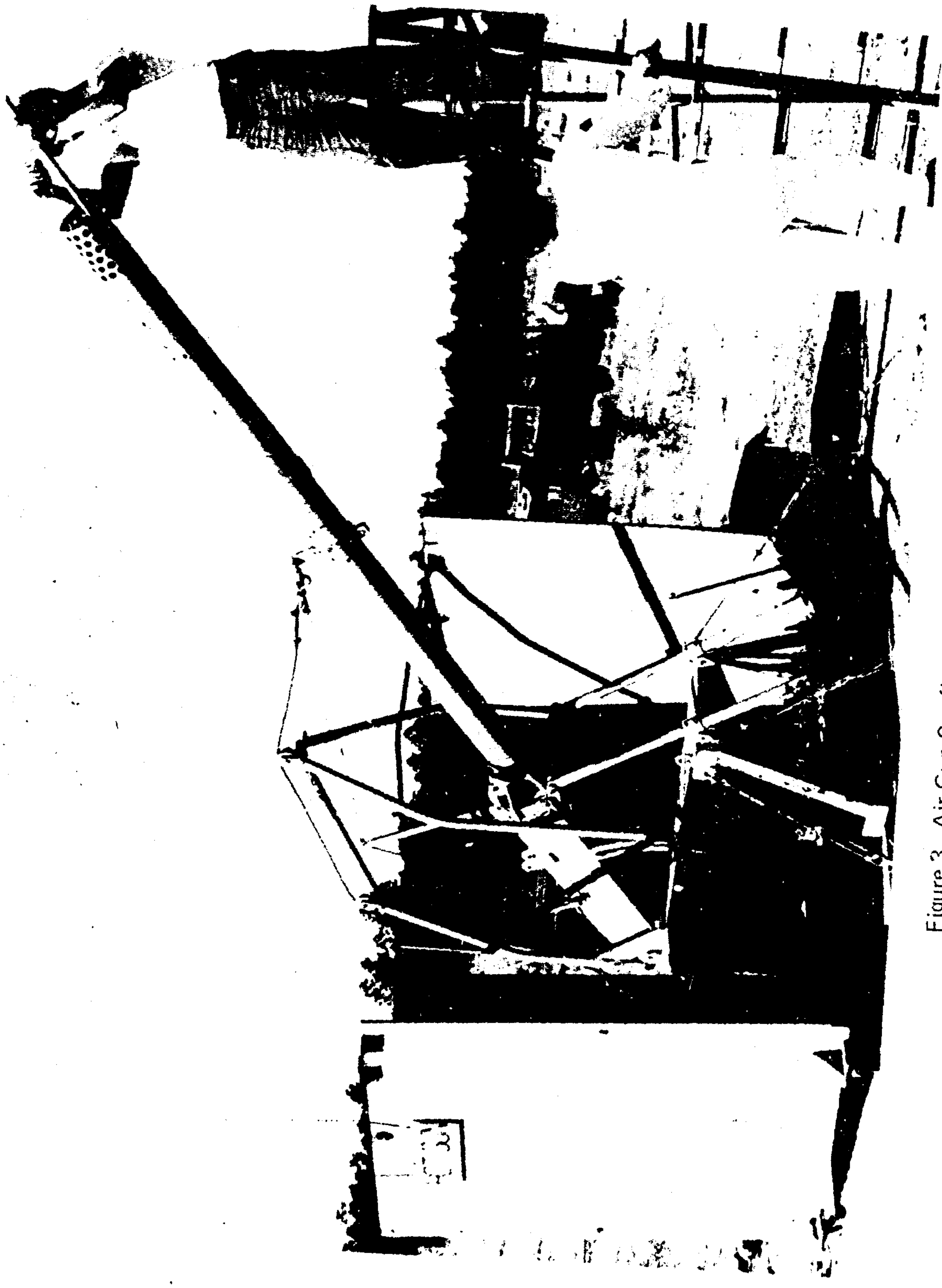

Figure 3. Air Gun Configuration at Loading

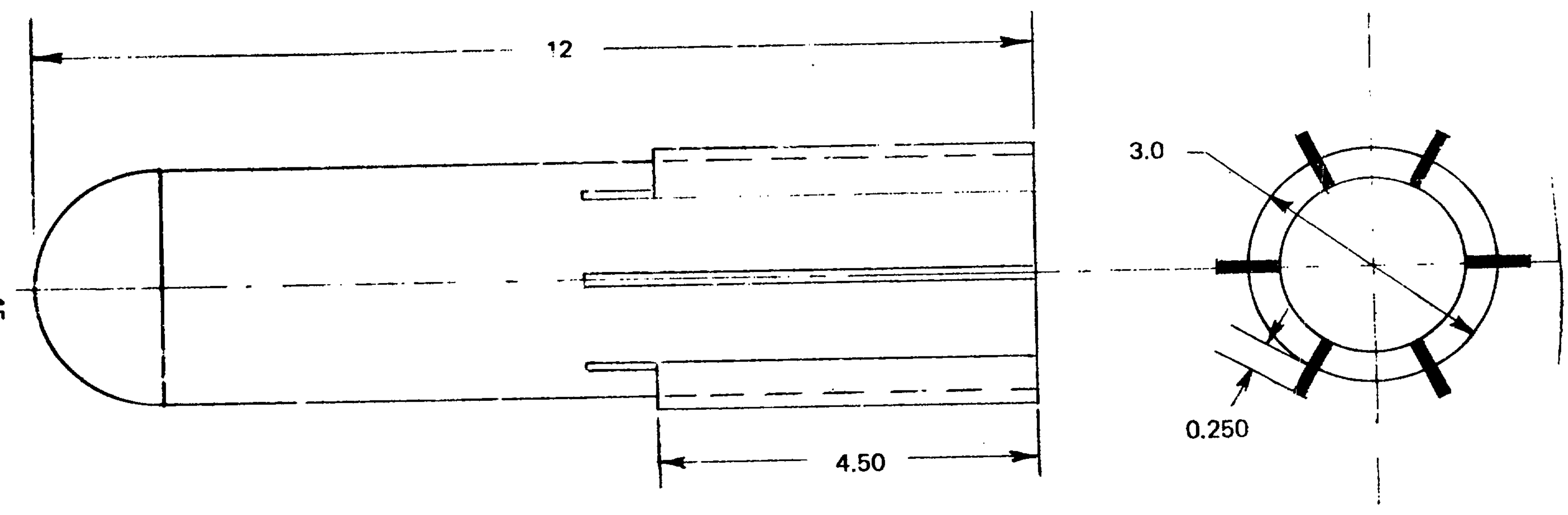


Figure 4. Twelve Inch S-Curve Model

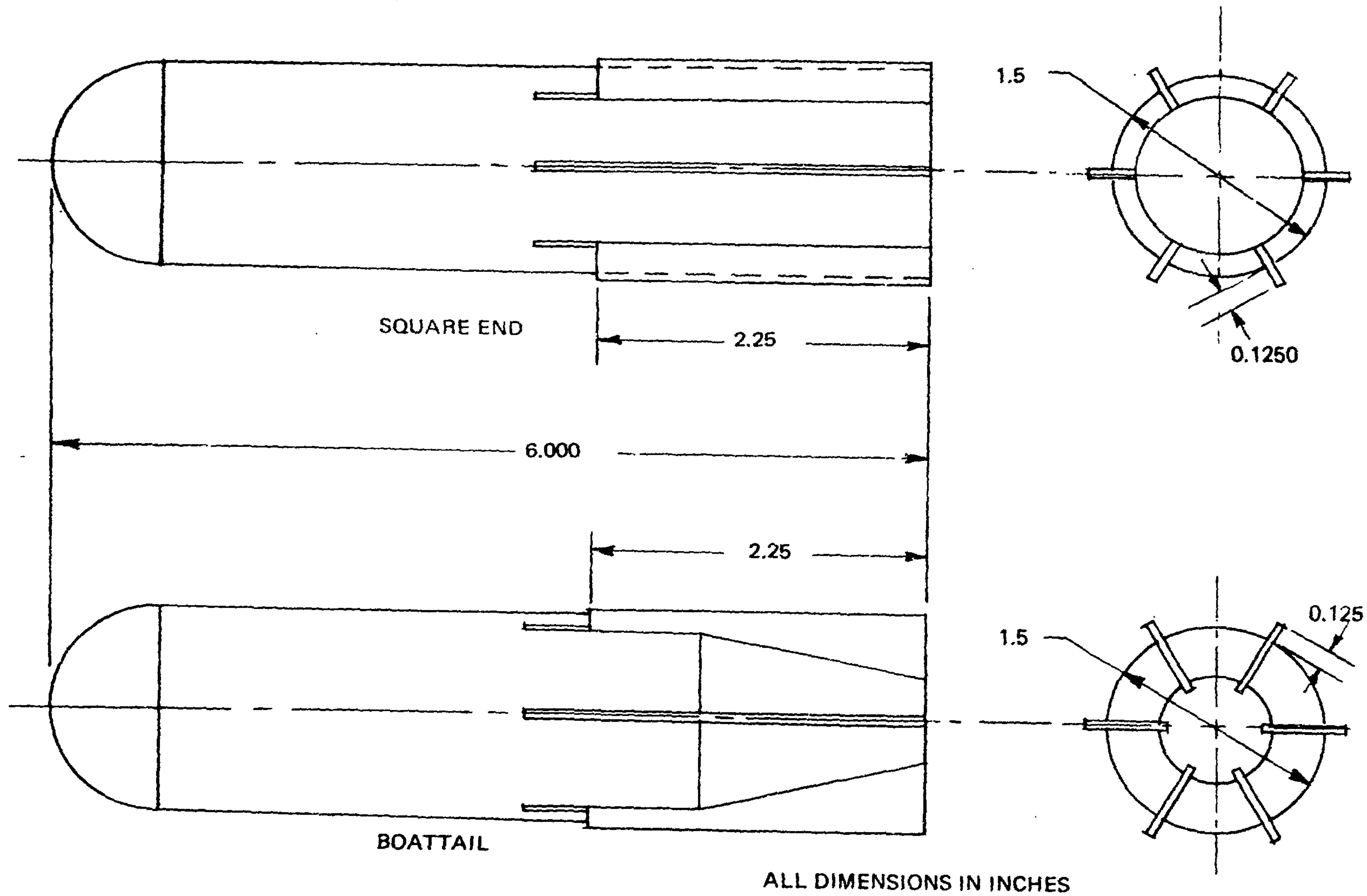


Figure 5. Six Inch S-Curve Models

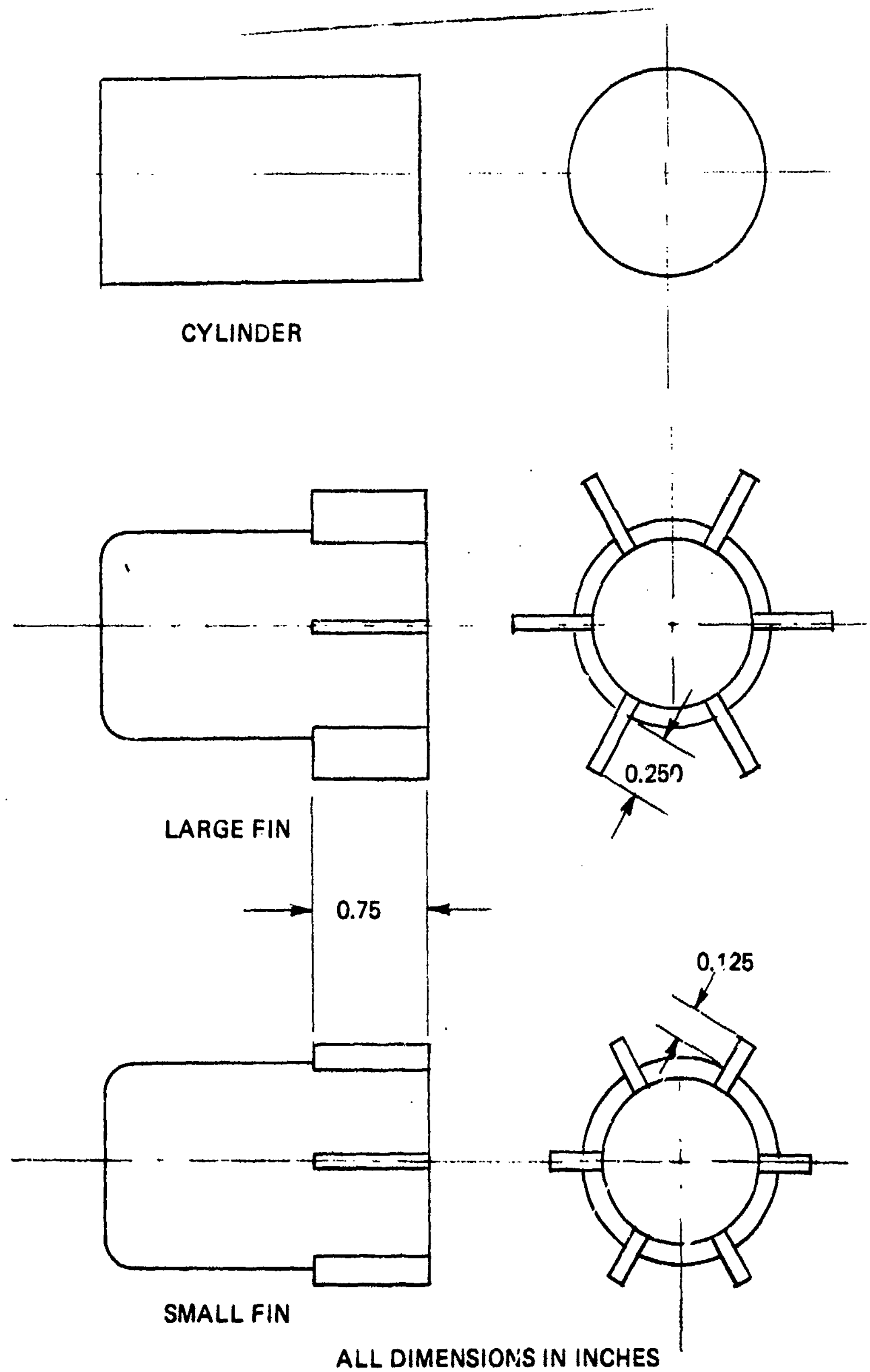


Figure 6. Two and One-Fourth Inch S-Curve Models

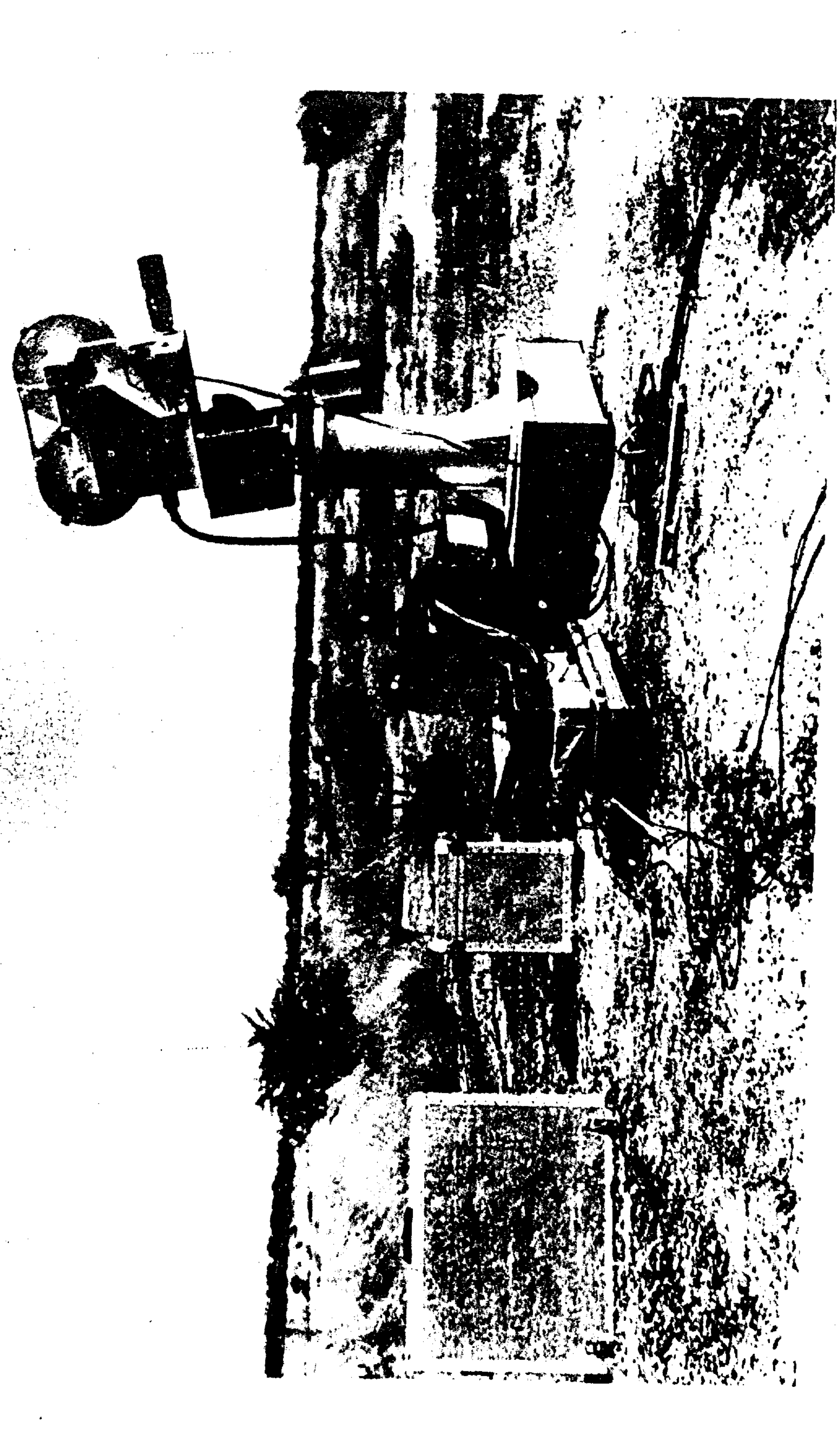

Figure 7. High Speed Camera Set Up

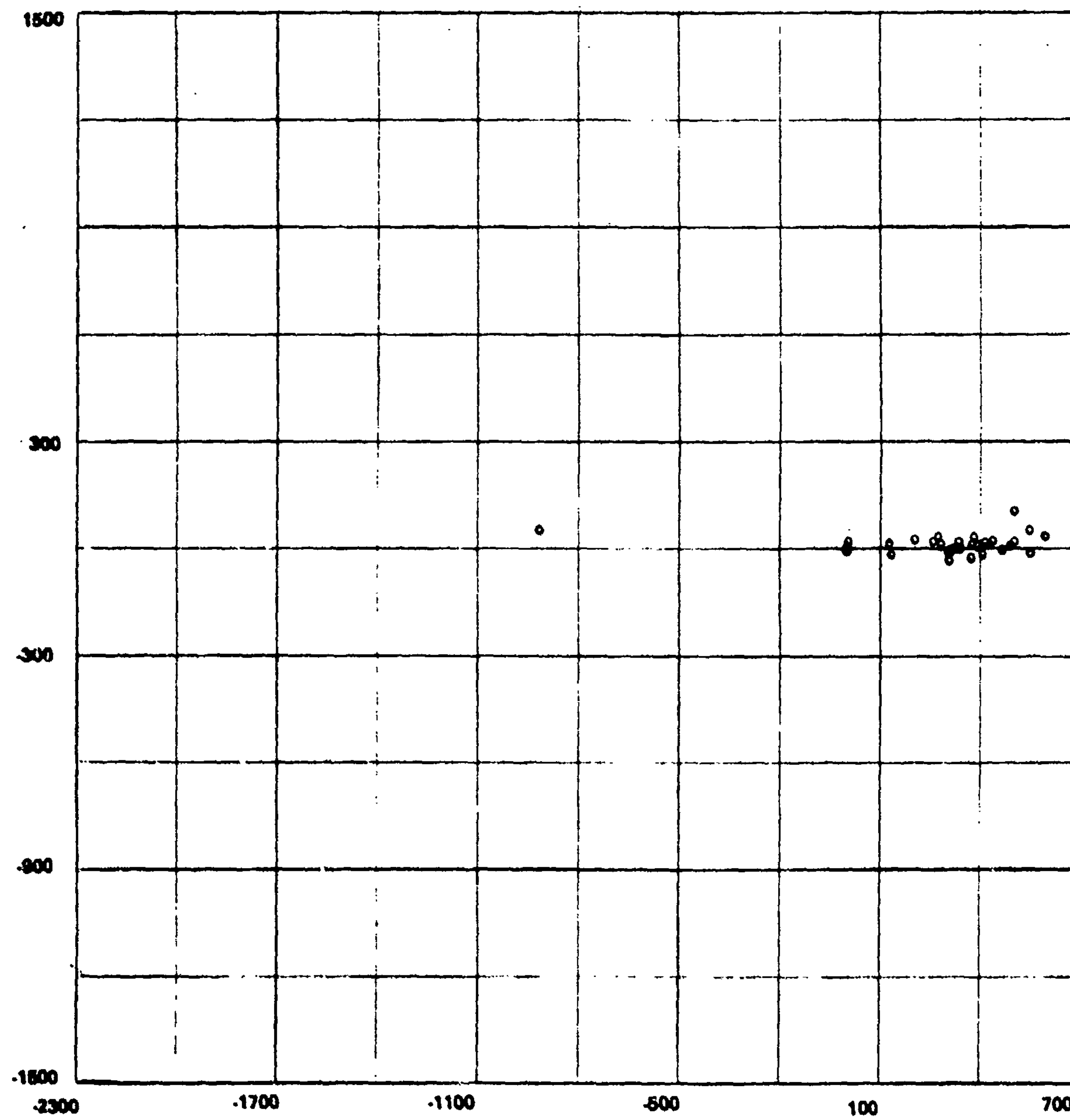


Figure 8. Impact Pattern for 12 Inch Ballistic Model

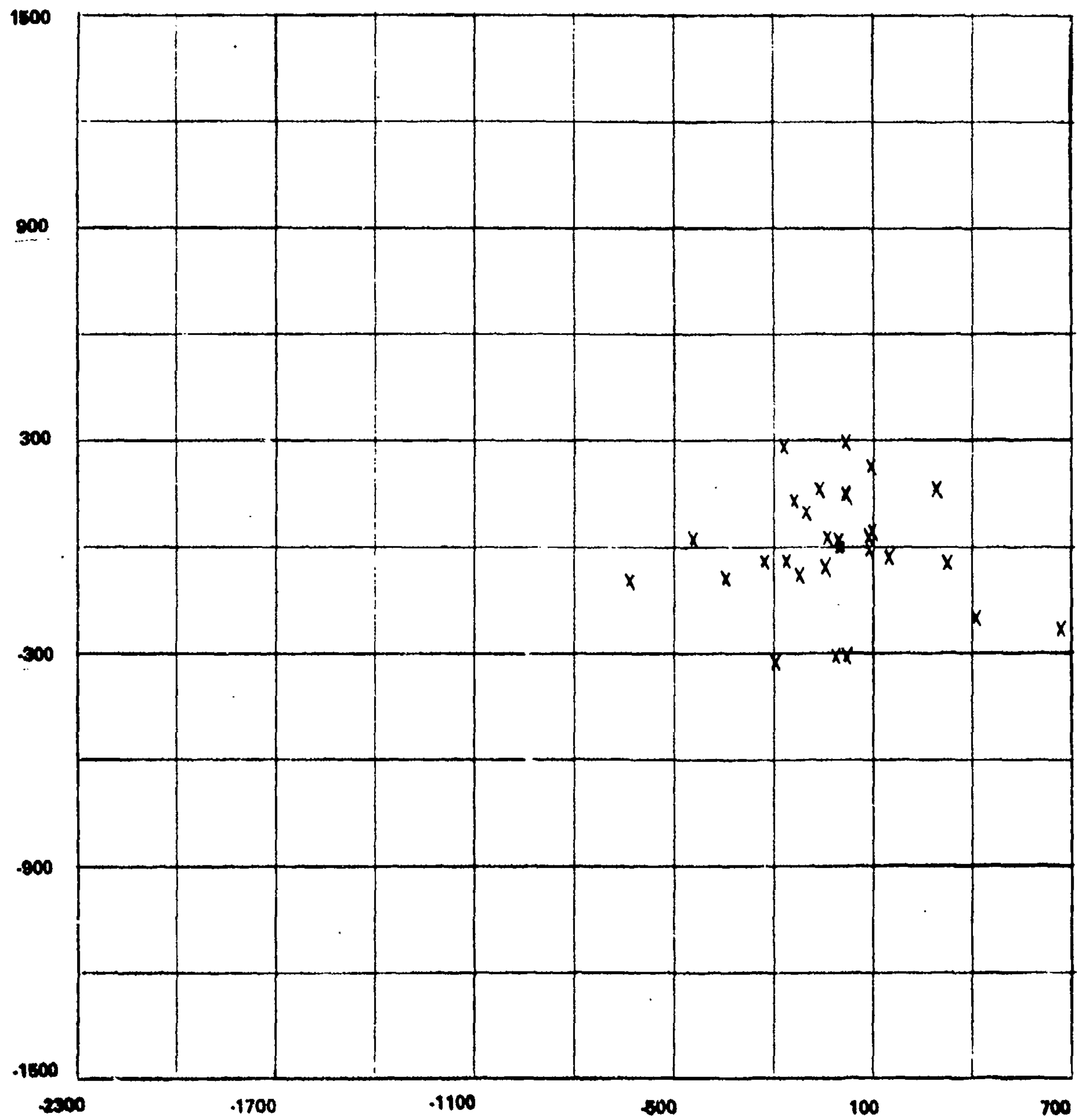


Figure 9. Impact Pattern for 12 Inch S-Curve Model

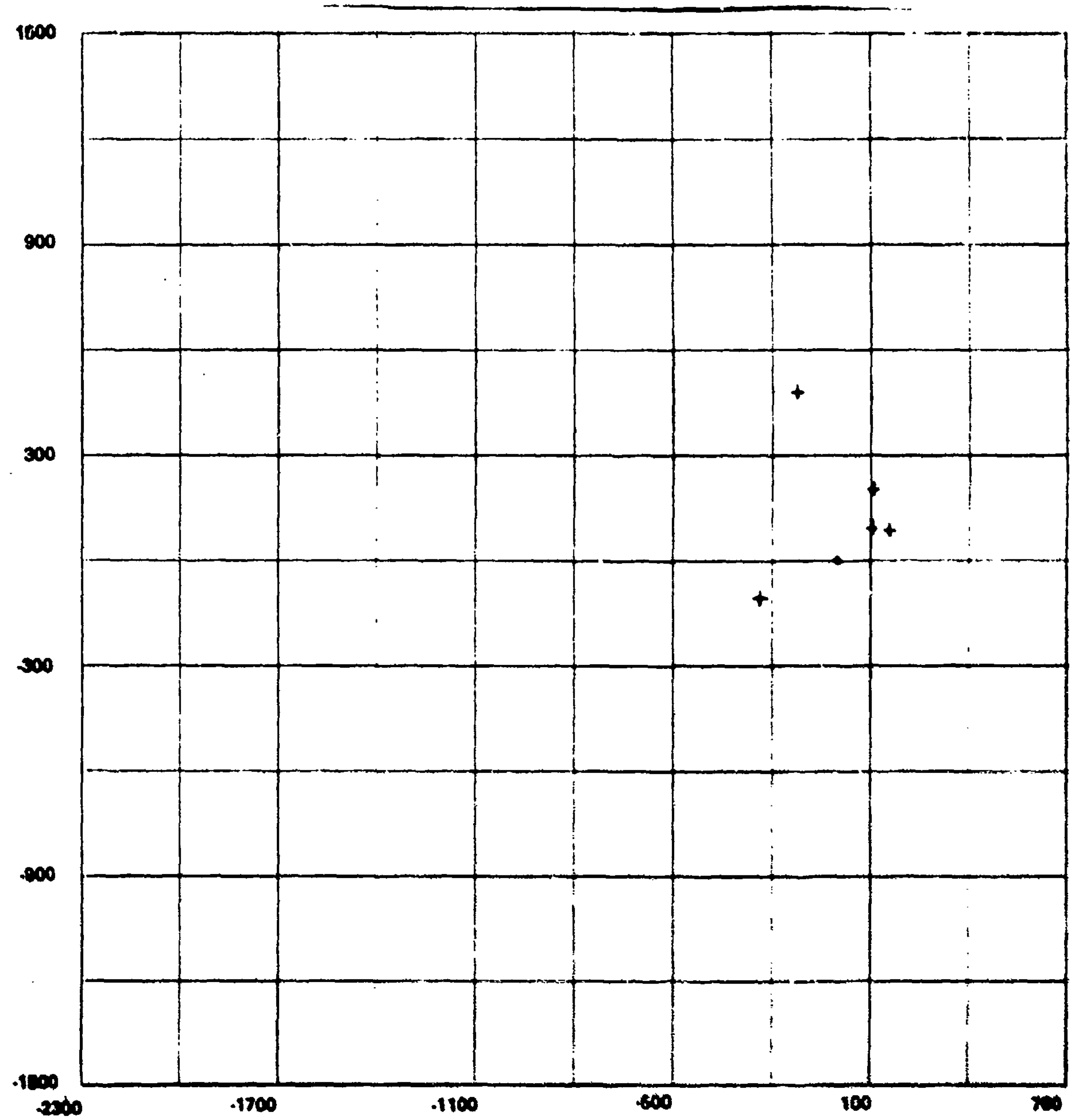


Figure 10. Impact Pattern for 12 Inch S-Curve Model with Bent Fin

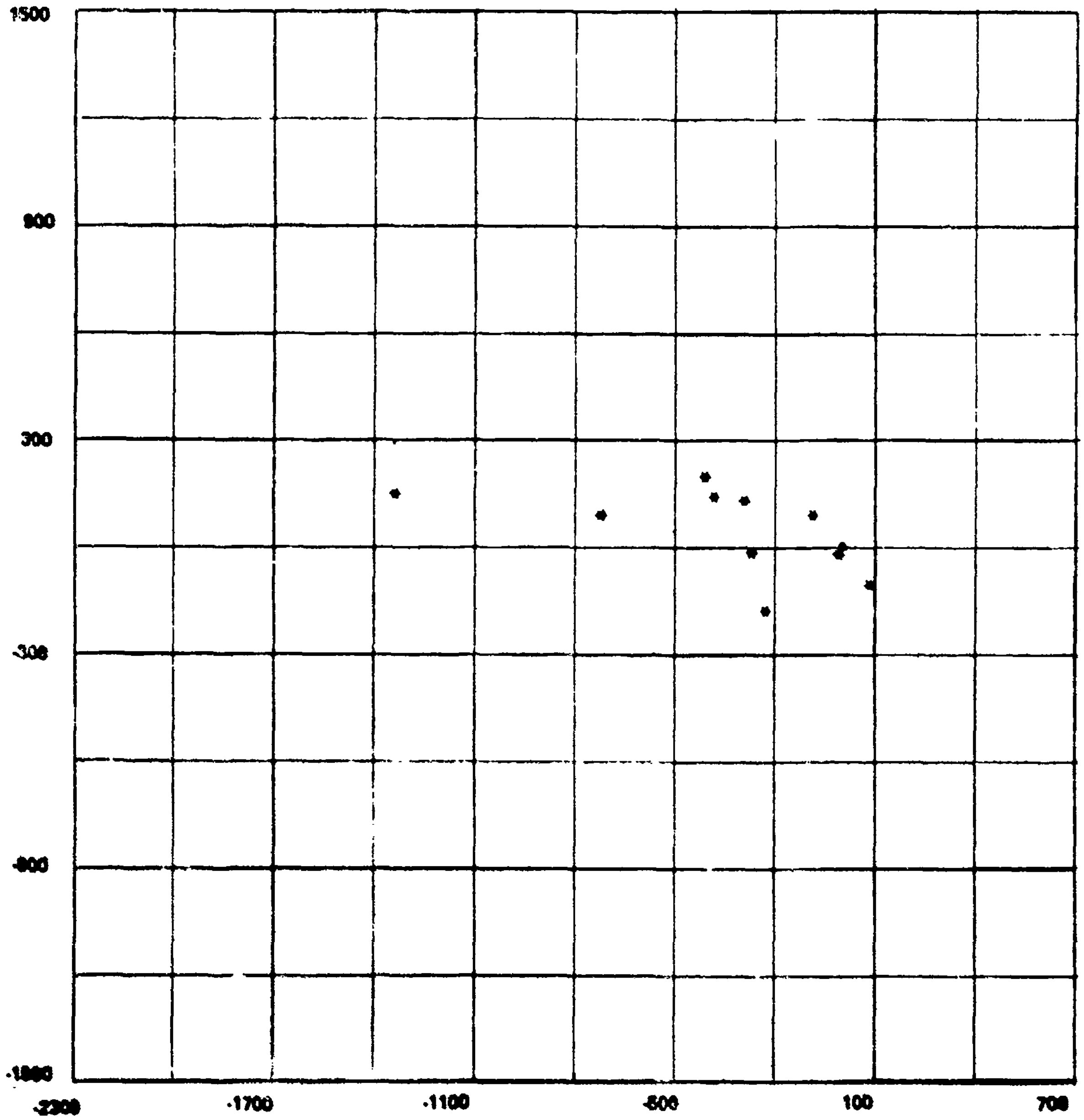


Figure 11. Impact Pattern for 12 Inch S-Curve Model with Scratched Nose

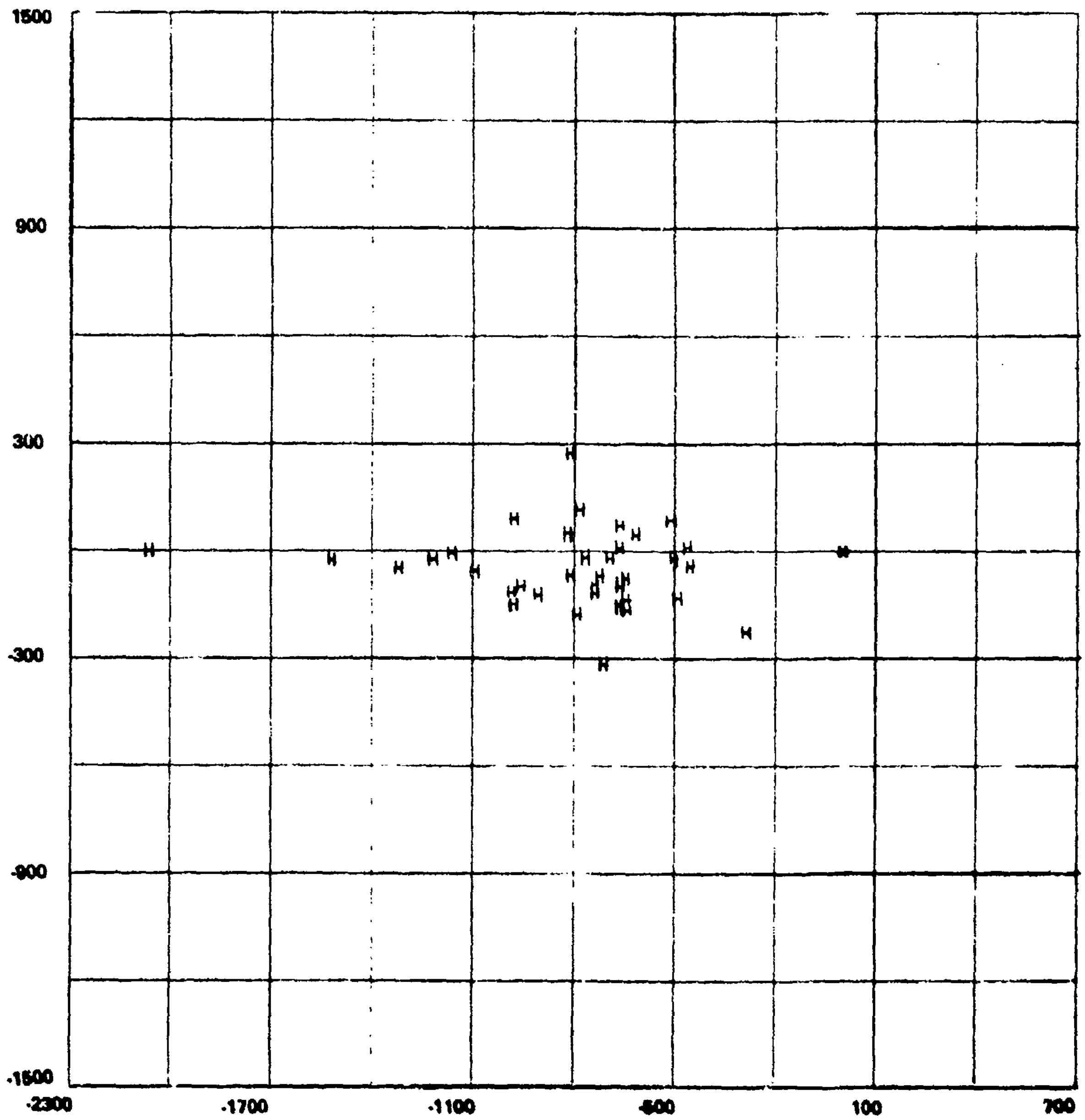


Figure 12. Impact Pattern for 6 Inch Square End Model

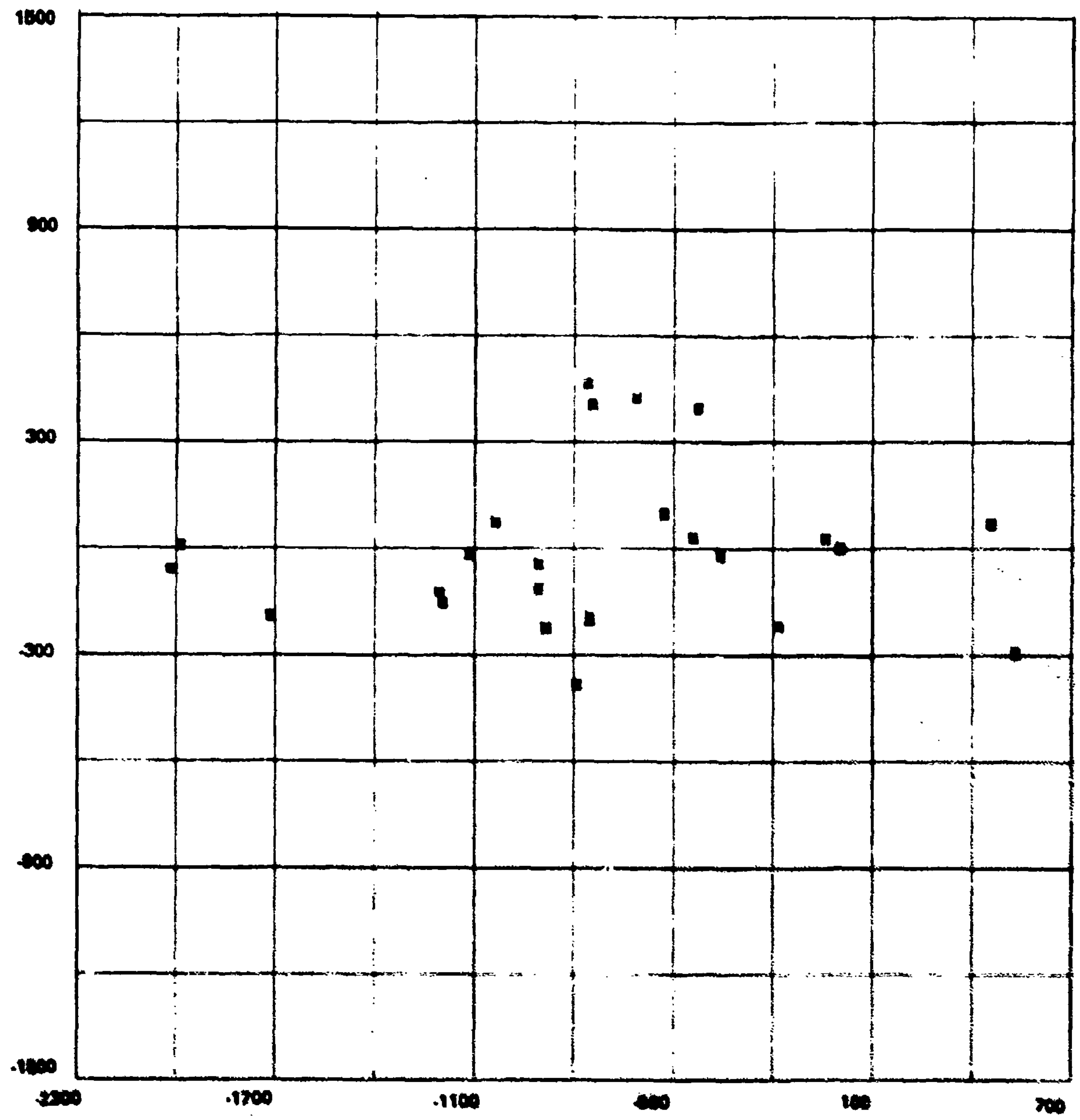


Figure 13. Impact Pattern for 6 Inch Boattail Model

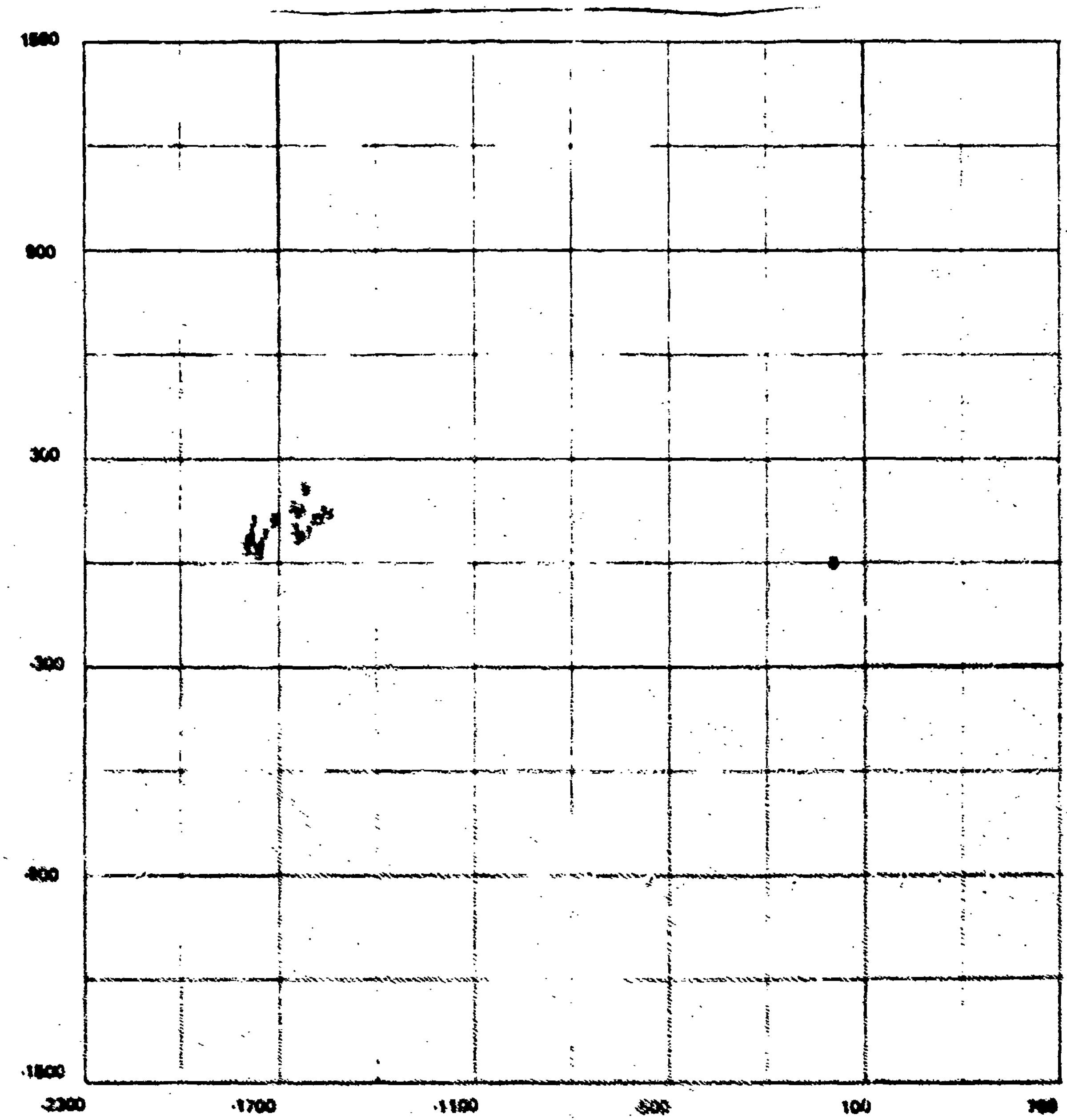


Figure 14. Impact Pattern for 2 1/4 Inch Plain Cylinder Model

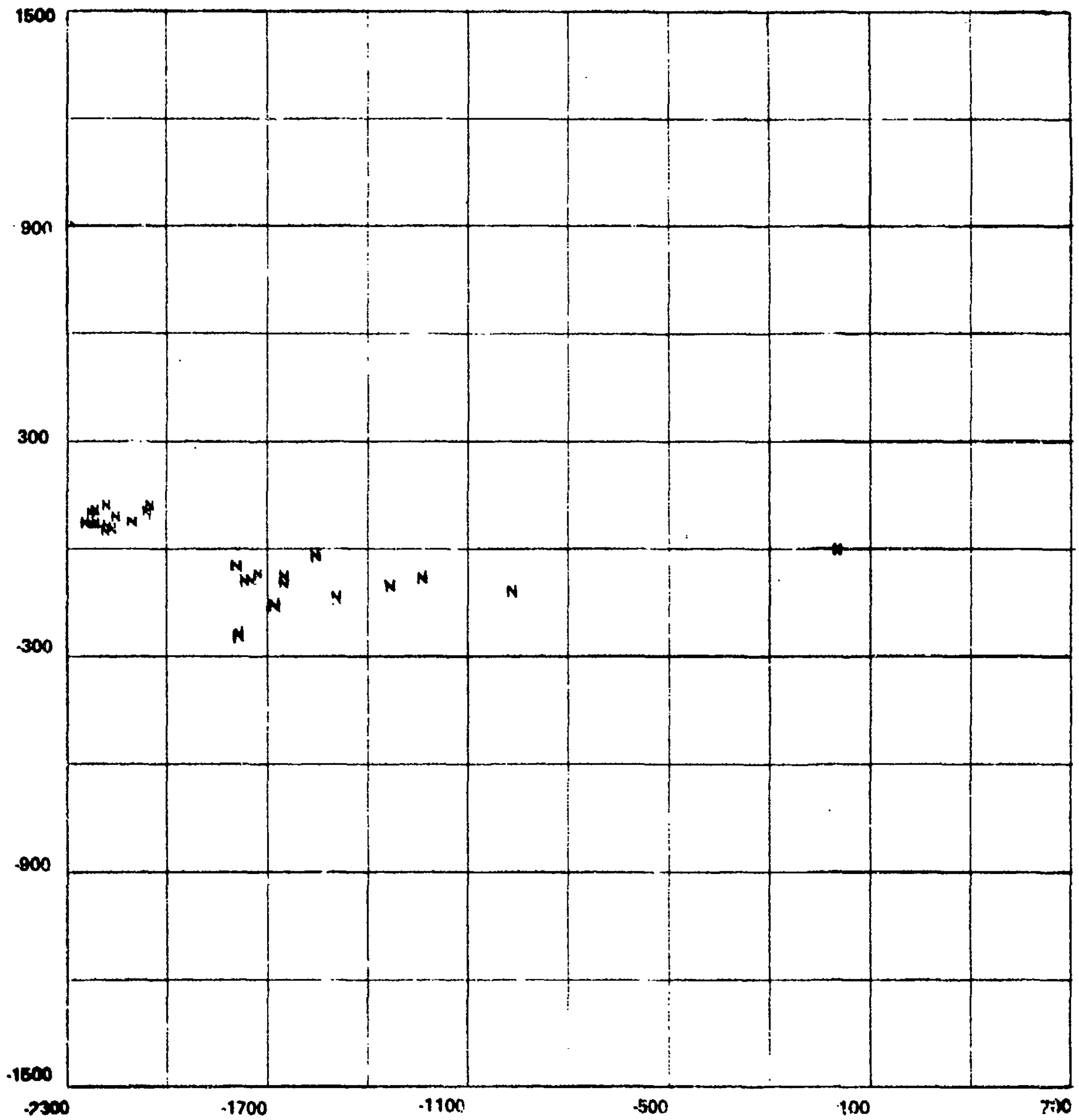


Figure 15. Impact Pattern for 2 1/4 Inch Large Fin Model

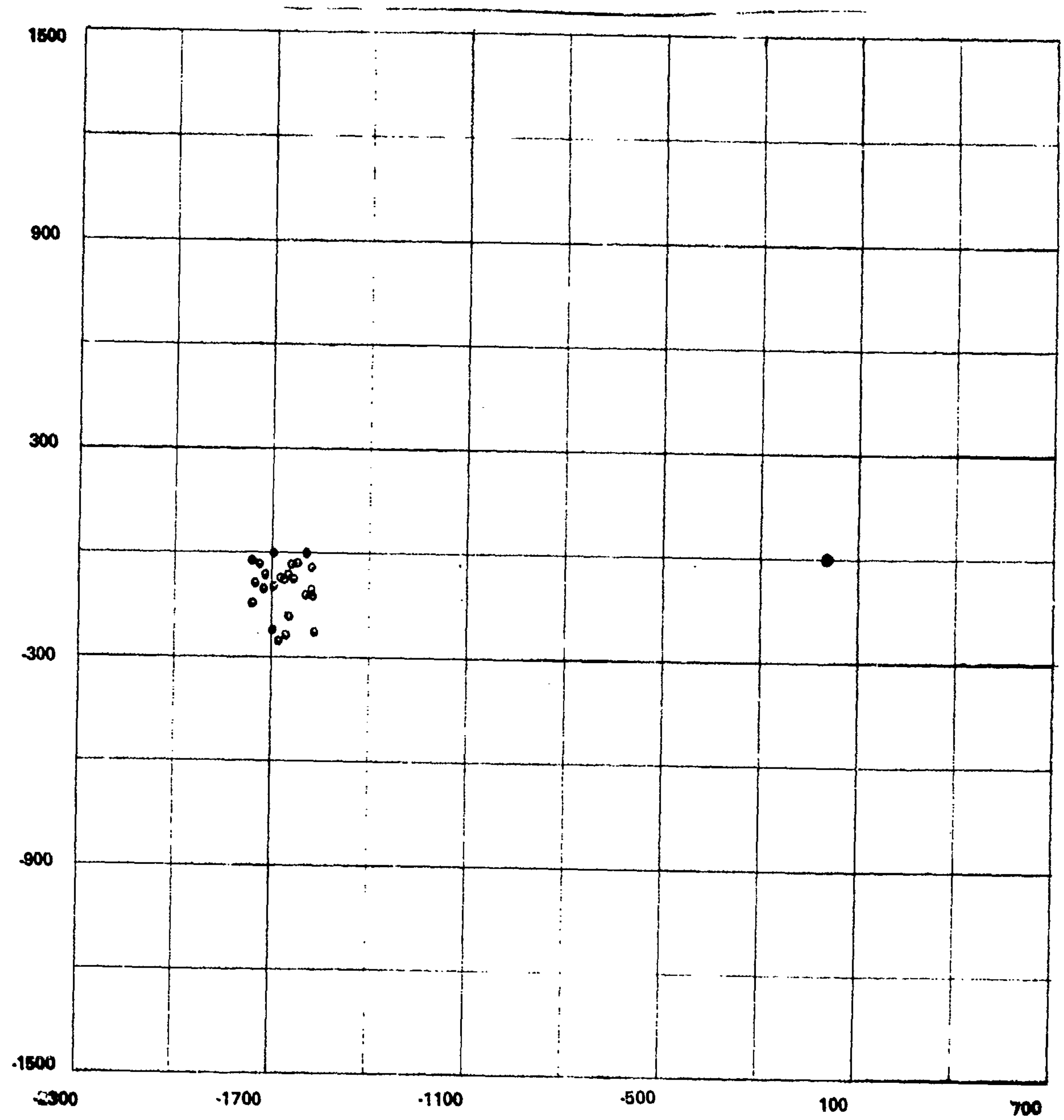


Figure 16. Impact Pattern for 2 1/4 Inch Small Fin Model


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